

Investigating A Quadrant Surface Coil Array for NQR Remote Sensing

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Abstract—this paper is on the design and fabrication of a surface coil array in a quadrant layout for NQR (Nuclear Quadrupole Resonance) remote sensing. In this paper, each of four surface coils will be parallel tuned and series matched with common electrical components to resonant at the same frequency. Coils will be in a “quadrant surface layout” in which all coils are in a four square arrangement to measure mutual coupling and SNR (Signal-to-Noise Ratio) at standoff distances perpendicular from each coil.

Index Terms— Nuclear Quadrupole Resonance, NQR, Coil Array, probe, Nuclear Magnetic Resonance, tuning, decoupling, RLC, mutual coupling, RLC

I. INTRODUCTION

IN Nuclear quadrupole resonance (NQR) is a radio frequency (RF) technique offering an unequivocal method of detecting the presence of quadrupolar nuclei, such as the nitrogen isotope ^{14}N , prevalent in many forms of high explosives, narcotics and drugs. Recently, the technique has received increasing attention as an important method for detecting land mines. This is because the NQR signal offers a unique signature, differentiating it from most other mine detection techniques that suffer from trying to detect non-unique features (such as the presence of metal) [1]. The application of this research is an NQR surface coil array that will detect the unique NQR signatures and the shape and size of an NQR material. The coil array will be in a quadrant layout rather than a cylindrical or linear layout in NMR (Nuclear Magnetic Resonance) coil arrays. The application of this research will not need to rotate around a sample like most NMR imaging applications, but capture NQR image in a stationary position.

In this paper, the term “probe” is defined by an RLC circuit, in which, the L represents a surface coil of a certain diameter. The R represents the resistance of the coil, and the C represents the parallel capacitance to create a resonance at a particular frequency. In real application this quadrant probe would have a large diameter transmitting coil and four smaller receiving probes, but this paper is focusing on the quadrant surface receiver probe as shown in Fig.1.



Fig.1, picture of NQR quad receiver surface probes on a wooden table. The upper right coil represents probe1 and continues counterclockwise around to probe4.

II. PROBE TUNING

Each of the four receiver coils are parallel tuned with a capacitor and series matched with a resistor. A 68pF (68.1pF measured) capacitor is placed in parallel with each of the 7 inch diameter, 1.1 turn, coils with a series coil resistance of 0.4Ω . This parallel LC circuit resonance is at 22.2MHz using inductance measurements, which involves of a smaller coil connected to a 2-port HP 8753D network analyzer. The smaller coil is placed in the center of each 7” diameter surface coils. The inductance of each 7” diameter surface coil equates to 755nH using

$$\omega_0 = \sqrt{\frac{1}{LC} - \left(\frac{r_{coil}}{L}\right)^2} \quad (1)$$

A 50Ω (51.08Ω measured) resistor is in series with the LC circuit to match and drop the Q of the coil. A low Q coil can be beneficial when detecting NQR materials with high temperature coefficients (kHz/deg C). Each of the four probes is tuned in a lab on a wooden table with a pair of 20 gauge twisted wires from the probe to an N-type connector, and the N-type connector feeds to the network analyzer. Because of the large gap between the probe connection points on the surface coil, the twisted wires were utilized instead of coaxial cables. The twisted 20 gauge wires with a 0.3Ω series resistance, creates a second resonance in imaginary impedance at 28.578MHz. Each of the individual probes were matched at 28.578MHz, which will be the frequency of focus for the rest of this paper. Below in Fig.2 is the measured S_{11} and phase

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1. REPORT DATE 23 OCT 2014		2. REPORT TYPE Final		3. DATES COVERED -	
4. TITLE AND SUBTITLE Investigating A Quadrant Surface Coil Array for NQR Remote Sensing				5a. CONTRACT NUMBER	
				5b. GRANT NUMBER	
				5c. PROGRAM ELEMENT NUMBER	
6. AUTHOR(S) James E. Burke				5d. PROJECT NUMBER	
				5e. TASK NUMBER	
				5f. WORK UNIT NUMBER	
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) U.S. ARMY RDECOM-ARDEC Sensors & Seekers Branch Bldg. 407 Rm 16 Picatinny Arsenal, NJ 07806-5000				8. PERFORMING ORGANIZATION REPORT NUMBER	
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)				10. SPONSOR/MONITOR'S ACRONYM(S)	
				11. SPONSOR/MONITOR'S REPORT NUMBER(S)	
12. DISTRIBUTION/AVAILABILITY STATEMENT Approved for public release, distribution unlimited					
13. SUPPLEMENTARY NOTES					
14. ABSTRACT					
15. SUBJECT TERMS					
16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT SAR	18. NUMBER OF PAGES 3	19a. NAME OF RESPONSIBLE PERSON
a. REPORT unclassified	b. ABSTRACT unclassified	c. THIS PAGE unclassified			

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angle of one of the four probes. The HP 8753D is an older network analyzer and provides older forms of data recording. For this reason, snapshots of the network analyzer screens will be shown in this paper as S-parameter measured results.

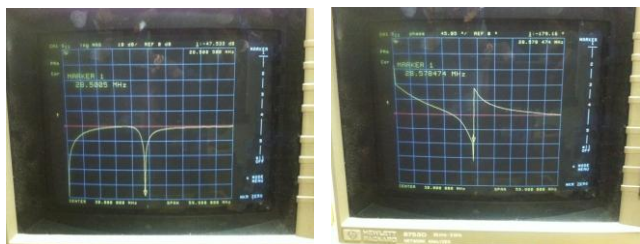


Fig.2 (left) measured S_{11} of -41dB at 28.578MHz even though screen shows 28.5005MHz, (right) measured phase angle of -179.16 degrees (which can also be -0.84 degrees) at 28.578MHz.

A circuit diagram in Fig.3 was developed in Ansoft RF Designer to determine the inductance of the twisted wires from the probes to N-type connector, and Fig.4 show the simulated results.

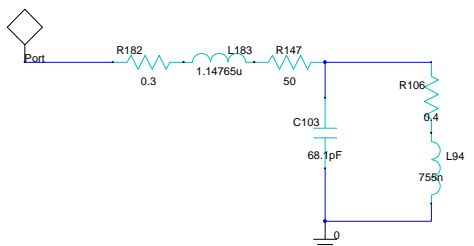


Fig.3, circuit diagram from Ansoft RF Designer showing the probe with shield wire resistance and inductance

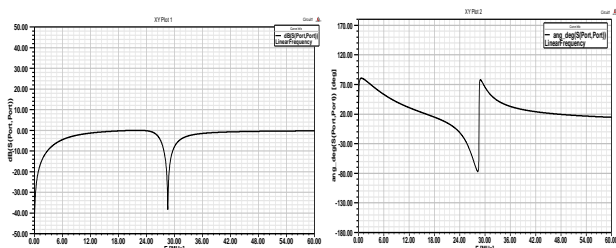


Fig.4 (left) simulated S_{11} of one of four probes, (right) simulated phase angle of one of four probes

In Fig.4, the return loss, S_{11} , is -38.2dB at 28.578MHz and phase is -0.84 degrees at 28.578MHz. A twisted wire inductance of 1.4765uH is shown to validate the simulated results against the measured results. Each of the four probes showed the same tuning to the 28.578MHz resonant frequency.

III. QUADRANT MUTUAL COUPLING

Now that the probes are tuned individually, the focus is now on the mutual coupling between probes in a quadrant layout. In the quadrant layout, all four individual probes were connected to a $\lambda/4$ line then to a 50 Ω load except when measurements are done. The probe(s) under measurement connects to the network analyzer 50 Ω input. Fig.5 shows the diagram of quadrant NQR receiver setup with the twisted

wires as part of the tuning elements and Fig. 6 shows some of the measured mutual coupling.

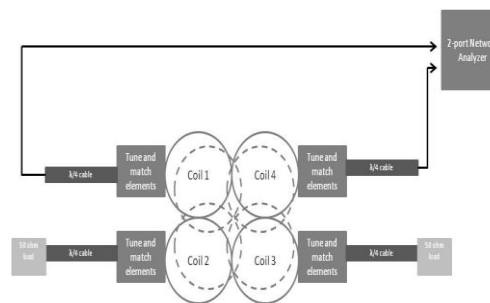


Fig.5, diagram of mutual coupling between probes. Measurements were taken of S_{14} , S_{23} , S_{12} , S_{34} , S_{13} , S_{24} , and S_{11} . Probe coils are roughly 1mm away from each other. Dotted lines show probe coils overlapping as a decoupling method.

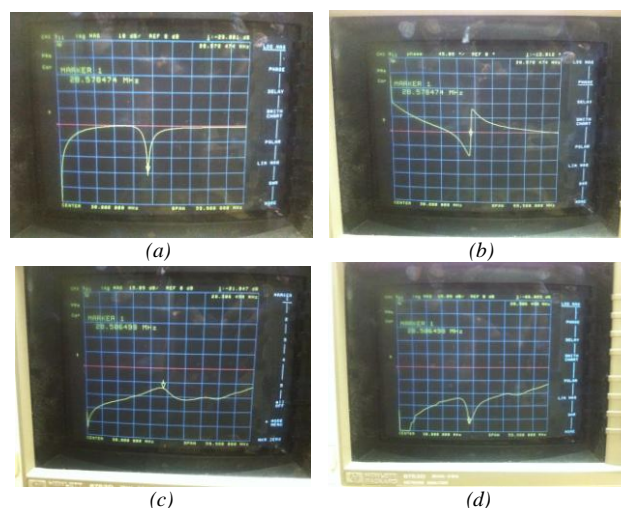


Fig.6(a) is the measured return loss S_{11} in quadrant surface setup of probe 1, 6(b) is the phase angle of (a), 6(c) is the mutual coupling S_{14} between probe 1 and probe 4, 6(d) is the mutual coupling of (c) after surface probes overlap in a quadrant surface setup as a decoupling method.

When comparing individual probe setup to quadrant probe setup, the S_{11} changes from -41dB to -29.8dB. For Fig.6b, the phase also changes from -0.84 to -13 degrees. Mutual coupling measurements were the same for S_{14} , S_{34} , S_{23} , and S_{12} ; therefore, the measured S_{14} in Fig.6c, d represents the return loss for all four. In Fig.6c, the mutual coupling shows sufficient probe to probe isolation, but increases in isolation at -63dB in Fig. 6d when probes overlap by 2 inches as a decoupling method. The drawback of applying the coil overlapping for decoupling is reduction in surface area detection. A benefit of overlap decoupling, besides greater probe isolation, is a reduction in center gap. This center gap can produce a received signal in all probes. This could produce a false since of the NQR material size.

IV. QUADRANT PROBE SIGNAL-TO-NOISE RATIO

After determining the mutual coupling of the quadrant surface probe receiver, investigation continues on the detection of CW (continuous wave) signals at 28.578MHz at different standoff distances perpendicular to the coil surfaces. The CW signal

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will represent the magnitude of quadrupole resonance that NQR materials will emit. NQR signals are very small in magnitude and sometimes as small as the noise level of the probe receiver, which makes investigating the SNR of the quadrant probe setup so important.

A. Setup

The CW signal is generated by an Agilent 33522A function generator at 1mV with high output impedance into a 2" diameter, 2 turn coil wrapped around a 4" long PVC pipe. The signal generator and transmitting coil is not included in the diagram in Fig.7 below. This transmitting coil is connected to the generator by a coaxial cable, and is placed in the middle of each probe with 2" standoff distance perpendicular to the surface. Standoff distance is incremented by 1" up to 7" inside every probe in the quadrant surface setup. Each received signal is sent through a quarter-wave cable to a wideband LNA (Low Noise Amplifier) ZFL-1000LN+ with a 25dB gain at 28.578MHz from Mini-Circuits. The output of the LNA is connected to a 50Ω input of a Tecmag Scout Spectrometer from Tecmag, Inc. The LNA moves to each probe for measurement.

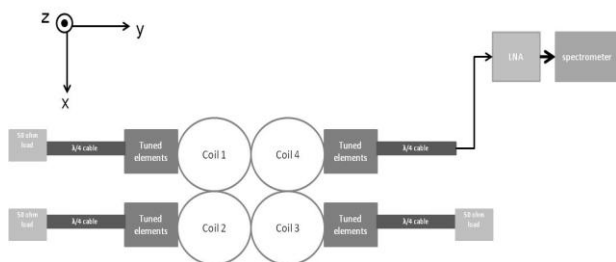


Fig.7, diagram of test setup for measuring SNR

B. Test Results

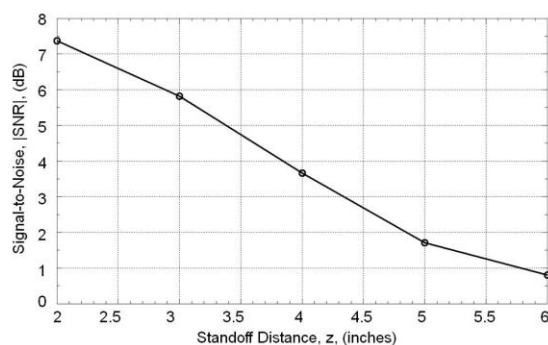


Fig.8, SNR at different standoff distances starting at 2inches away. The black line represents SNR at different standoff distances with coils roughly 1mm away from each other in a quadrant surface setup.

The noise level of the probe was measured at 196.87uV. Since the SNR was shown to be the same for all four probes, Fig.8 shows one of the four. The SNR drops to zero once standoff distance detection is greater than 6 inches.

V. CONCLUSION

In this paper, each of four surface coils were parallel tuned and series matched with 50Ω resistors to resonant at 28.578MHz. Developing a surface coil with the end points being close together will alleviate the need for twisted wires between the probe and an N-type connector used in this paper. With the end points close together, only a quarter-wave coaxial cable is needed.

Probes were in a “quadrant surface layout” in which all coils were in a four square arrangement to measure mutual coupling. The SNR was measured at standoff distances from each probe. The applications of this research could include buried explosive detection and entry control point monitoring.

REFERENCES

- [1] Jakobson, A., “Multi-channel Detection of Narcotics and Explosives Using NQR Signal” 1-4244-0309-X/06/\$20.00 ©2006 IEEE



James E. Burke received a Bachelors of Science degree in electrical engineering, Florida International University, Miami, Florida, USA 2005. James Burke received a Master's of Engineering in microelectronics and photonics, Steven's Institute of Technology, Hoboken, New Jersey, USA 2009. He is currently an electronics engineer with the U.S. Army RDECOM-ARDEC, Picatinny Arsenal, New Jersey, USA ('05-present).